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SURFACE DEFORMATION IMAGE ANALYZER

STATEMENT OF GOVERNMENT INTEREST

[0001] The invention described herein may be manufactured and used by or for the Government of the United States of America for Governmental purposes without the payment of any royalties thereon or therefore.

CROSS REFERENCE TO OTHER PATENT APPLICATIONS

[0002] None.

BACKGROUND TO THE INVENTION

(1) FIELD OF INVENTION

[0003] The present invention relates to the field of medical and laboratory equipment, and specifically to a device for analyzing deviations in hard surfaces, tissue and other surfaces.

(2) DESCRIPTION OF THE PRIOR ART

[0004] Magnification technologies known in the art to inspect solid surfaces have been used to aid in surface deformation analysis. However, these methods were not specifically developed for scanning a surface in detail in order to determine the existence of a surface abnormality and to provide diagnostic

information, such as depth, density or other quantifiable properties.

[0005] One problem is that surface deformations and abnormalities which require precise measurement and comparison cannot be accurately diagnosed by visual inspection of images, and the cause of a deformation or repair suggestions may be highly subjective.

[0006] For example, a minute crack in a battery casing may be caused by physical strain on the casing or by chemical exposure. Because repair techniques for each cause may differ (e.g., adding structural support or adding a chemical-resistant coating); it is important to determine the cause of a surface deformation. Current magnification technologies do not provide sufficient analytical detail to make such diagnoses.

[0007] Similarly, magnetic resonance imaging (MRI) and magnification technologies for obtaining detailed diagnostic images are known in the art and have been adapted to identify variations in skin and tissue surfaces. However, these methods were not specifically developed for measuring skin surface abnormalities and have significant diagnostic limitations with respect to analyzing diagnostically significant surface variations.

[0008] Existing medical imaging technologies, such as MRI, positron emission tomography (PET) and ultrasound, provide

detailed images of abnormalities used for diagnosis and treatment. These tools, however, require visual interpretation and analysis by a user attempting to diagnose or monitor a condition. The user may supplement the visual analysis by using additional image analysis software. Any visual interpretation and analysis allows for introduction of errors and subjective diagnostic conclusions. Additionally, when monitoring a condition, comparison of images over time is laborious if not impossible.

[0009] For example, human and animal tissue (including skin and internal tissue) develop a wide range of complex and subtle abnormalities which may not be accurately diagnosed by visual inspection. A single abnormality may (based on an MRI image) appear to be an abrasion when the abnormality is a cancerous growth. Similarly, a particular lesion may be caused by sun exposure, chemical exposure, or weakened immunity. Without analyzing the lesion in more detail, it may be difficult to determine the exact cause of the lesion and to provide the proper treatment.

[0010] Another problem is that there is no accurate way to monitor the changing characteristics of a surface deformation during repair or healing other than taking successive images; visually comparing them; or making multiple measurements for comparison. However, these methods are prone to inaccuracies

because the methods require technicians to subjectively identify an area to capture for each image through their own visual observation. There are no known hardware devices which can accurately monitor a defined area. Wound tracing, saline-volume determinations and biochemical markers alternative methods have been used to monitor the healing process. These methods are similarly problematic, as the methods require direct physical contact with a wound.

[0011] It is therefore desirable to have a device which accurately measures surface deformations and eliminates the error caused by subjective and inconsistent evaluation of images in the attempted diagnosis of abnormalities. It is further desirable to have a device and method of use which yields information that can monitor the effectiveness of treatment and shorten the time frame and cost for treating non-healing wounds.

SUMMARY OF THE INVENTION

[0012] The present invention provides a device which includes integrated hardware and software components to measure and monitor surface abnormalities and deformations on solid surfaces and animal and human tissues. The device includes a display panel and a control panel secured to the upper surface of a housing. A plurality of sensor arrays, including a displacement sensor array, temperature sensor array, ultrasonic sensor array

and ultraviolet sensor array, are attached to the lower surface of the housing on two scanner belts. The angle of the sensor arrays relative to the housing may be adjusted by using a primary adjustment element.

[0013] A processing component receives input from the sensor arrays to create a plurality of data objects which are stored in an image object database. A retrieval hardware processing component retrieves image objects from the image object database and identifies attributes to display an image and quantitative values on the display panel. An area hardware processing component runs at least one algorithm to determine the area of a surface abnormality. In some embodiments, a further hardware processing component may be provided to receive user input in order to update images and to select a deformation region for area calculation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] **FIG. 1** is a bottom view of an exemplary embodiment of sensor arrays for a surface deformation image analyzer;

[0015] **FIG. 2** is a side view of an exemplary embodiment of a sensor for the surface deformation image analyzer;

[0016] **FIG. 3** is an exemplary embodiment of a human-machine interface for the surface deformation image analyzer;

[0017] **FIG. 4A** is an exemplary embodiment of the surface deformation image analyzer scanning a deformation which is a protrusion;

[0018] **FIG. 4B** is an exemplary embodiment of the surface deformation image analyzer scanning a deformation which is an intrusion;

[0019] **FIG. 5** is an exemplary embodiment of an ultraviolet sensor array of the surface deformation image analyzer scanning a deformation;

[0020] **FIG. 6** is an exemplary embodiment of the processing components of the surface deformation image analyzer;

[0021] **FIG. 7** is an exemplary operational flowchart for completing a scan using the surface deformation image analyzer;

[0022] **FIG. 8A** is an exemplary irregular deformation which may be scanned using the surface deformation image analyzer;

[0023] **FIG. 8B** is an exemplary embodiment of a polygon formed around the irregular deformation used to calculate the area of the deformation using Pick's theorem;

[0024] **FIG. 8C** is an exemplary embodiment of non-deformation regions having an area which may be calculated using Simpson's rule; and

[0025] **FIG. 8D** is an exemplary non-deformation region which is rotated and subdivided prior to calculating the area using Simpson's rule.

Terms of Art

[0026] As used herein, the term "**data object**" refers to a data structure which includes data, functions or both, or which invokes functions when data is changed.

[0027] The term "**deformation region**" refers to an area of a surface having an inconsistent surface characteristic. For example, a deformation region may include, but is not limited to, a cut, crack, intrusion, protrusion, strain, scar, abrasion, birthmark, mole, discoloration, puncture, bump, rough texture, smooth texture, fracture, difference in temperature, and other surface characteristic or combination of characteristics.

[0028] The term "**Human-Machine Interface**" or "**HMI**" refers to a structure adapted to relay information between (to or from) a computer component or computer system and a human user or to store information which may be retrieved and/or manipulated by the human user.

[0029] The term "**non-deformation region**" refers to the non-deformed portion of a surface which is adjacent to a deformed surface and which is captured based on an algorithm used for calculating the area of the surface to be analyzed. A non-deformation region does not contain significant surface deformation.

[0030] The term "**Pick's theorem**" refers to a method of calculating the area of a polygon based on the number of grid points located within and on the perimeter of the polygon. Pick's theorem uses the equation

$$Area = r^2 \left(i + \frac{b}{2} - 1\right)$$

where i is the number of grid points located within the polygon, b is the number of grid points located on the perimeter of the polygon, and r is the scaling factor. The term "**Pick's theorem polygon**" refers to a polygon created for the purpose of performing an area calculation using Pick's theorem.

[0031] The term "**sensor**" refers to any structure that measures a physical property, such as temperature, displacement, reflections, and combinations of these and other properties, and converts the measured physical property into a signal to be processed and read by an observer. The term "**sensor array**" refers to a plurality of similar sensors operatively coupled to work in cooperation.

[0032] The term "**Simpson's rule**" refers to a method of calculating the area under a closed polynomial curve. When calculating an area relative to an x axis, Simpson's rule uses the equation

$$Area = \int_a^b f(x)dx \approx \frac{h}{3}\left[y_0 + 4y_1 + 2y_2 + \ldots + 4y_{n-1} + y_n\right]$$

where y_i are variable heights lying perpendicular to the x axis and $h = \frac{b-a}{n}$ is the length of the curve divided into n even numbered partitions. When calculating an area relative to a y axis, Simpson's rule uses the equation

$$Area = \int_c^d f(y)dy \approx \frac{h}{3}\left[x_0 + 4x_1 + 2x_2 + \ldots + 4x_{n-1} + x_n\right]$$

where x_i are variable heights lying perpendicular to the y axis and $h = \frac{d-c}{n}$ is the length of the curve divided into n even numbered partitions.

[0033] The term "**surface deformation**" refers to any abnormality on a surface. Surface deformations may be two- or three-dimensional deformations, including, but not limited to; protrusions, intrusions, cracks, punctures, abrasions, areas of discoloration, areas of temperature variation, cuts, strains, scars, birthmarks, moles, bumps, rough textures, punctures, smooth textures, and combinations of these and other abnormalities.

DETAILED DESCRIPTION OF INVENTION

[0034] For the purpose of promoting an understanding of the present invention; references are made in the text to exemplary embodiments of software that can process, smooth, and grid bathymetric data into a uniform distribution data set. It should be understood that no limitations on the scope of the invention are intended by describing these exemplary embodiments. One of ordinary skill in the art will readily appreciate that alternate but functionally equivalent bathymetric mapping software may be used. The inclusion of additional elements may be deemed readily apparent and obvious to one of ordinary skill in the art. Specific elements disclosed herein are not to be interpreted as limiting, but rather as a basis for the claims and as a representative basis for teaching one of ordinary skill in the art to employ the present invention. It should be understood that the drawings are not necessarily to scale; instead, the drawings emphasize the principles of the invention. In addition, in the embodiments depicted herein, reference numerals in the various drawings refer to identical or near identical structural elements.

[0035] The method for identifying a uniform distribution data set for producing bathymetric surface maps enhances the accuracy of measurements by using processing components to characterize

changes in bathymetric data. The software can characterize changes in bathymetric data by using a grid pattern that contains a plurality of grid nodes and by processing data corrupted by outliers and measurement errors.

[0036] **FIG. 1** is a bottom view of an exemplary embodiment of a sensor for a surface deformation image analyzer **100**. In the exemplary embodiment shown, the image analyzer **100** contains four primary sensor arrays: a displacement sensor array **20**, a temperature sensor array **30**, an ultrasonic sensor (transducer) array **40**, and an ultraviolet image sensor array **50** which includes digital cameras **55**. These sensor arrays are arranged parallel to one another and perpendicular to scanner belts **70**. The scanner belts **70** move the sensor arrays along a housing **90** in order to complete a scan of an area of interest.

[0037] The sensor arrays **20**, **30**, **40** and **50** are secured on an array assembly **73** to move in coordinated unison with the scanner belts **70**. In the exemplary embodiment shown, the array assembly **73** is the structure securing the sensor arrays **20**, **30**, **40** and **50** and engaging the scanner belts **70**.

[0038] As illustrated, the displacement sensor array **20** includes multiple displacement sensors **22** placed in parallel across the image analyzer **100**. In the exemplary embodiment shown, the displacement sensors **22** are laser displacement sensors. However, in other exemplary embodiments, the

displacement sensors may be any sensor which measures displacement.

[0039] During operation, the displacement sensors **22** are activated sequentially to ensure sensor readings are not corrupted by adjacent sensor emissions. Ultimately, the frames captured during scanning are fused together to make a cohesive image from the displacement sensor array **20**. Sequential activation of the displacement sensors **22** and the scanning speed of the image analyzer **100** are coordinated to ensure image processing is not compromised.

[0040] In the exemplary embodiment shown, there are thirty-one displacement sensors **22** arranged in a continual line perpendicular to the scanner belts **70**. The displacement sensors **22** are positioned so that each is in physical contact with the next in order to provide continual measurements across the displacement sensor array **20** and to avoid gaps in measurements. In further exemplary embodiments, the number and positioning of the displacement sensors **22** may vary - based on the size of a housing **90** or sized to achieve a desired level of accuracy in measuring an area of interest.

[0041] The temperature sensor array **30** is an array of multiple temperature sensors **32**. In the exemplary embodiment shown, the temperature sensors **32** are laser temperature sensors. However, in further exemplary embodiments, the temperatures

sensors **32** may be any sensor known in the art which measures temperature. Each temperature sensor **32** measures the produced or absorbed temperature of an area of interest. The temperature readings from each sensor **32** are fused to produce a spectrographic image.

[0042] In the exemplary embodiment shown, there are ten temperature sensors **32** arranged in a line perpendicular to the scanner belts **70**. The temperature sensor array **30** is parallel with the displacement sensor array **20**. The temperature sensors **32** are positioned to achieve accurate readings across the surface of an area of interest. In further exemplary embodiments, the number and positioning of the temperature sensors **32** may vary - based on the size of the housing **90** or to achieve a desired level of accuracy in measuring an area of interest. In some exemplary embodiments, an infrared heat sensing camera or array of cameras may be used in place of or in conjunction with the temperature sensor array **30**.

[0043] Depending on the surface of interest and the type of deformation anticipated; it may be helpful to treat the surface of interest with a heat source, such as radiant heat, or cooling treatment, such as liquid nitrogen. Surface deformations or abnormalities may be more visible after being subject to the change in temperature. In some exemplary embodiments, the

surface deformation image analyzer **100** may directly include a heating or cooling component.

[0044] The ultrasonic sensor array **40** includes a plurality of ultrasonic sensors **42**. The ultrasonic sensors **42**, or transducers, are active for the duration of a scan; unlike the displacement sensors **22** which are activated sequentially. In the exemplary embodiment shown, the operating frequency of each ultrasonic sensor **42** is unique to ensure there is no interference from neighboring transducers **42**.

[0045] In the exemplary embodiment shown, there are nine ultrasonic sensors **42** arranged in a line perpendicular to the scanner belts **70** and parallel with the displacement sensor array **20** and the temperature sensor array **30**. The ultrasonic sensors **42** are positioned so that each sensor is in physical contact with the next in order to provide continual readings across the ultrasonic sensor array **40**. In further exemplary embodiments, the number and positioning of the ultrasonic sensors **42** may vary - based on the size of the housing **90** or to achieve a desired level of accuracy in measuring an area of interest.

[0046] The digital cameras **55** are arranged along the ultrasonic sensor array **40**. In the exemplary embodiment shown, the digital cameras **55** are high-resolution, high-speed digital cameras and work in conjunction with the ultraviolet image sensor array **50**. The ultraviolet image sensor array **50** is made

of a plurality of ultraviolet LEDs (light emitting diodes) **52**. The ultraviolet light provided by the ultraviolet LEDs **52** ensures visual detection by the digital cameras **55** of otherwise invisible organic material on the area of interest. For example, a defect may be otherwise invisible but by the presence of organic material is made visible by the ultraviolet image sensor array **50** and is captured by the digital cameras **55**.

[0047] In the exemplary embodiment shown, there are two digital cameras **55** arranged within the ultrasonic sensor array **40** and seventeen ultraviolet LEDs **52** positioned in a line parallel with the displacement sensor array **20**, the temperature sensor array **30**, and the ultrasonic sensor array **40**. In further exemplary embodiments, more or fewer digital cameras **55** or ultraviolet LEDs **52** may be used for more detailed imaging. In still further exemplary embodiments, the arrangement of the ultraviolet LEDs **52** and the digital cameras **55** may vary in order to provide accurate and detailed imaging of an area of interest.

[0048] The housing **90** is illustrated as primarily rectangular with the scanner belts **70** running parallel to one another, and perpendicular to the sensor arrays **20**, **30**, **40** and **50**, along one length of the housing. In the exemplary embodiment shown, the scanner belts **70** are half-rotational belts. The speed of scanner belts **70** is programmable to be coordinated with the functions of the sensor arrays **20**, **30**, **40** and **50**. In further

exemplary embodiments, the housing **90** may be configured differently and the scanner belts **70** may be oriented differently on the housing in order to accommodate different housing shapes. In still further exemplary embodiments, the scanner belts **70** may be positionable along the housing **90** to accommodate a specific area of interest.

[0049] **FIG. 2** is a side view of an exemplary embodiment of a sensor for the surface deformation image analyzer **100**. A top surface **92** contains Human-Machine Interface (HMI) **200** (not shown), which includes sensor controls and sensor indicators and displays images to be analyzed. A side surface **94** contains primary element adjustment **82** and handles **84**. The array assembly **73** and the digital camera **55** are visible along a bottom surface **93** of the housing **90**.

[0050] The primary element adjustment **82** is used to alter the angle declination of the bottom surface **93** or the array assembly **73** when the surface of interest is not sufficiently flat for accurate measurements. The angle of declination of the bottom surface **93** may be adjusted up to approximately fifty degrees relative to the housing **90**. An adjustable angle of declination up to at least forty-five degrees is preferred.

[0051] In the exemplary embodiment illustrated, a single primary element adjustment **82** is provided to cause one end of the bottom surface **93** to move downward; thereby, causing an

angle of declination. In further exemplary embodiments, additional primary element adjustment components may be used to allow the bottom surface **93** to angle at any end.

[0052] In the exemplary embodiment shown, the primary element adjustment **82** is a slide which adjusts the angle of declination of the bottom surface **93** or the array assembly **73**. In further exemplary embodiments, the angle of array assembly **73** relative to a surface of interest may be adjusted through any means known in the art. In further exemplary embodiments, the bottom surface **93** may also be adjusted closer or further from a surface of interest. The bottom surface **93** may be adjusted to between 0 and 45 centimeters, relative to the bottom of the housing **90**.

[0053] The handles **84** are contoured rods which are removably attached to the side surface **94**. In some embodiments, the handles **84** may be ergonomically contoured or include gripping or cushioned coatings to help a user grab the housing **90**. In the exemplary embodiment shown, the handles **84** are threaded to engage threaded apertures **86** and secure to the housing **90**. In further exemplary embodiments, the handles **84** may secure to the housing **90** through any means known in the art to provide a secure, though releaseable, connection, including, but not limited to, contours, pins, bolts, brackets, screws, and combinations thereof. In some exemplary embodiments, the handles **84** may be secured to any side of the housing **90**.

[0054] **FIG. 3** is an exemplary embodiment of the Human-Machine Interface (HMI) **200** for the surface deformation image analyzer **100**. In the exemplary embodiment shown, the HMI **200** is an LCD display with a graphical user interface (GUI) **201**, a detail display **202** and an adjustment display **203**. The GUI **201** displays scanned images of an area of interest, as well as details such as time, date, and scale. In further exemplary embodiments, the GUI **201** may be configured to display multiple images and overlay images. In some embodiments, the GUI **201** may be a touch screen.

[0055] The detail display **202** is configured to give specific information in an easy-to-read format. For example, in the current embodiment, the detail display **202** is shown displaying the battery life and the current magnification. Both of these details are important to monitor while using the image analyzer **100** in the field. In further exemplary embodiments, the detail display **202** may be configured to display additional or alternative details, including, but not limited to, declination of the array assembly **73**, distance from a surface of interest, remaining battery life (in minutes), the status of specific sensors (i.e., if any sensor is malfunctioning), progress of a current scan and combinations thereof.

[0056] In the exemplary embodiment shown, the adjustment display **203** includes selectable options for a variety of features of the surface deformation image analyzer **100** including

a power button **204**, a save button **205**, a reset button **206**, an adjust display button **207**, a freeze button **208**, a test sensor selector **209**, a zoom dial **210**, a scan speed selector **211** and an image/data selector **212**. In further exemplary embodiments, the adjustment display **203** may include additional or fewer selectable options. In still further exemplary embodiments, the adjustment display **203** may be a touch screen; thereby, allowing for additional customization.

[0057] In the exemplary embodiment shown, the power button **204**, the save button **205**, the reset button **206**, the adjust display button **207**, the freeze button **208** are standard push button selectors known in the art. For example: pressing the power button **204** cycles power; pressing the save button **205** saves current scan data; pressing the reset button **206** resets the GUI **201** (without interfering with saved data); pressing the adjust display button **207** allows a user to alter the view on the GUI and move the image around without closing the form; and pressing the freeze button **208** disables the testing sequence offered by the test sensor selector **209**.

[0058] In the exemplary embodiment shown, the test sensor selector **209** is used to test the sensor arrays **20**, **30**, **40** and **50**. Each array **20**, **30**, **40** and **50** is selectable for individual testing. When going through a testing sequence, each sensor **22**, **32**, **42** and **52** in an array **20**, **30**, **40** and **50**, respectively, is

tested in sequence. In the exemplary embodiment shown, an indicator light in the center of the sensor selector **209** illuminates green at the completion of successful testing of an array **20**, **30**, **40** and **50**. If a sensor fails, the sensor selector **209** illuminates red. In some embodiments, the GUI **201** may guide a user through troubleshooting or repair if a sensor fails testing.

[0059] The zoom dial **210** allows a user to select magnification. In the exemplary embodiment shown, the zoom dial **210** allows adjustable magnification up to nine times. In further exemplary embodiments, magnification may be increased or decreased on a continual scale or adjusted using a structure other than a positionable dial.

[0060] Similarly, the scan speed selector **211** allows a user to adjust the scan speed. The selector **211** is dependent on the speed of an initial scan by which the selector establishes as "normal." Further scans may be adjusted faster or slower than the initial scan. In further exemplary embodiments, scan speed may be selected using a structure other than a dial and scan speed may be continually adjustable along a continuum. In still further exemplary embodiments, scan speed may be provided in specific speeds of inches per second or centimeters per second.

[0061] The image/data selector **212** allows a user to select the image displayed on the GUI **201**. For example, images

collected from the arrays **20, 30, 40** and **50** may be viewed independently of each other or fused or layered over one another. Pressing the reset button **206** clears displayed images.

[0062] While in the exemplary embodiment shown, various dials and press buttons are used to allow a user to select between various functions and views offered by the surface deformation image analyzer **100.** In further exemplary embodiments, different structures which allow a user to select functions may be used. For example, touch screens, knobs, slides, toggles, and combinations of these and other structures may be used.

[0063] **FIG. 4A** and **FIG. 4B** illustrate the surface deformation image analyzer **100** in use with different surface deformations. In the exemplary embodiment shown in **FIG. 4A**, a surface of interest **101** contains a deformation **102** which is a protrusion, while the surface of interest in **FIG. 4B** is shown with a deformation which is an intrusion.

[0064] In the exemplary embodiments shown, the displacement sensor array **20** and the ultrasonic sensor array **40** are visible on the bottom surface of the housing **90.** The displacement sensors **22**, which in the exemplary embodiment shown are laser displacement sensors, emit laser beams **26** which measure the displacement of the deformation **102.** The displacement sensors **22** determine the amount of time for an emitted laser beam **26** to

be reflected back to the displacement sensors in order to calculate the height or depth of the deformation **102**.

[0065] The ultrasonic sensors **42** of the ultrasonic sensor array **40** emit ultrasonic acoustic emissions which are similarly reflected back to the ultrasonic sensors to provide additional detail not observable when using the displacement sensor array **20**. For example, ultrasonic acoustic emissions are able to probe the depths and walls of minute openings which may otherwise be missed by using only the displacement sensor array **20**. The ultrasonic sensor array **40** performs best when the surface of interest **101** is a hard surface. However, the ultrasonic sensor array **40** may be used when the surface of interest **101** is comparatively soft.

[0066] Also illustrated in **FIG. 4A** and **FIG. 4B** are ultraviolet markers **56**. The ultraviolet markers **56** are ultraviolet(UV)-reflective markers. In the exemplary embodiments described, at least two ultraviolet markers **56** must be placed with the surface of interest **101** to allow proper overlay of the image generated by the ultraviolet image sensor array **50** over other images. In further exemplary embodiments, additional ultraviolet markers **56** may be used to increase the accuracy of image overlays. The ultraviolet markers **56** will register during a scan and become part of an image until calculations are completed.

[0067] **FIG. 5** illustrates an exemplary embodiment of the ultraviolet image sensor array **50** in more detail. In the exemplary embodiment shown, the ultraviolet LEDs **52** (not shown) and hidden by the ultrasonic sensor array **40**, wash the surface of interest **101** with the deformation **102** in ultraviolet (UV) light. The digital cameras **55** are sensitive to ultraviolet light and photograph the surface of interest **101** as the array assembly **73** passes over the deformation **102**.

[0068] The ultraviolet markers **56** are shown on the perimeter of the deformation **102**. Because the ultraviolet markers **56** are UV-reflective, the digital cameras **55** will capture the location of the ultraviolet markers. The ultraviolet markers **56** are used as reference points when overlaying images generated by the sensor arrays **20**, **30**, **40** and **50**.

[0069] **FIG. 6** is an exemplary embodiment of the processing components for the surface deformation image analyzer **100**. The sensors arrays **20**, **30**, **40** and **50** perform a scan of a surface of interest. In the exemplary embodiments described, each sensor array **20**, **30**, **40** and **50** scans the area of interest simultaneously. However, in further exemplary embodiments, each sensor array **20**, **30**, **40** and **50** may be activated individually. In still further exemplary embodiments, a user may be able to select one or more of sensor arrays **20**, **30**, **40** and **50** in order to create a customized scan.

[0070] Information from each sensor array **20, 30, 40** and **50** is received by an assembling processor **615** which creates a plurality of quasi-unique data objects **620a-d,** each data object containing attributes corresponding to the data sensed by one of the sensor arrays **20, 30, 40** and **50.** In some exemplary embodiments, the data objects **620a-d** are further processed by an image processor **630** and error analysis processor **635.** The image processor **630** performs digital image processing techniques, such as image calibration, pixilation and other techniques known in the art, to produce color encoded image data objects **632a-d.**

[0071] The error analysis processor **635** runs algorithms to remove or mitigate data abnormalities to produce corrected image data objects **637a-d.** The color encoded image data objects **632a-d** and image data objects **637a-d** are then received by a storage processor **640** which processes the pairs of data objects (e.g., data objects from the processor **630** and a processor **640** containing attributes from the same sensor array) for storage in an image object database **645** as image data objects **655a-d.**

[0072] While in the exemplary embodiment shown, the image processor **630** and the error analysis processor **635** operate simultaneously. In further exemplary embodiments, the processors **630** and **635** may operate in sequence. In still further exemplary embodiments, the error analysis processor **635** may be omitted or activated by a user request. In other

exemplary embodiments, image processing and error analysis may be skipped or omitted. Quasi-unique data objects **620a-d** are then relayed directly to the storage processor **640** for storage in the image object database **645** as image data objects **655a-d.**

[0073] An image object retrieval processor **650** retrieves the image objects **620a-d** and is configured with software to identify data attributes within images and to update the HMI **200** to display the image and quantitative values associated with the image and stored within the image objects as an attribute. For example, an image object **620a** corresponding to information obtained through the displacement sensor array **20** may contain attributes such as the displacement values at any given point in a deformation region.

[0074] An image update processor **660** is configured with software to receive input from a user **690** and to communicate with the retrieval processor **650** to update the image on the HMI **200** based on user input. For example, the user **690** may request viewing the image generated by both the displacement sensor array **20** and the temperature sensor array **30** overlaid for comparison. The image update processor **660** receives the request and communicates with the retrieval processor **650** to retrieve the desired image objects and to create the composite image for display.

[0075] In the exemplary embodiment shown, the image data object **655a** is laser displacement image data object. The image data object **655a** contains attributes including, but not limited to, the quantitative displacement value at any given point in an area of interest, the change in displacement between given points in an area of interest and any other information which is sensed by the displacement sensor array **20**.

[0076] The displacement image produced by the image data object **655a** is displayed on the GUI **201** as a spectrogram image with areas of elevation and depression represented on a color spectrum (red, orange, yellow, green and blue). Using the HMI **200**, a user can determine the exact displacement at a specific point in the image, as well as the coordinates of the point.

[0077] The image data object **655b** is a laser temperature image data object. The image data object **655b** contains attributes including, but not limited to, the quantitative temperature value at any given point in an area of interest, the change in temperature between given points in an area of interest and any other information which is sensed by the temperature sensor array **30**. The thermal image produced by the image data object **655b** shows variation in temperature as represented by graduated changes in the color spectrum (red, orange, yellow, green and blue). Using the HMI **200**, a user can

determine the exact temperature at a specific point in the image, as well as the coordinates of the point.

[0078] The image data object **655c** is ultrasonic image data object. The image data object **655c** contains attributes including, but not limited to, ultrasonic reflection values at any given point in an area of interest, the difference in reflection values between points in an area of interest, and any other information which is sensed by the ultrasonic image sensor array **40**. In the exemplary embodiments described, the acoustic image produced by the image data object **655c** is displayed on the GUI **201** in a format almost identical to that of the displacement image - using the same color spectrum. The acoustic image will show minute imperfections in greater detail than the displacement image. In further exemplary embodiments, the acoustic image and displacement image may be differentiated by color spectrum or another visual cue.

[0079] The image data object **655d** is an ultraviolet image data object. The image data object **655d** contains attributes including, but not limited to: ultraviolet reflection values at any given point in an area of interest; the difference in reflection values between points in an area of interest; and any other information which is sensed by the ultraviolet sensor array **50**. In the exemplary embodiments described, the UV image produced by the image data object **655d** is displayed on the GUI

201 as a high-resolution scan image. Organic material lodged in a surface deformation is illuminated by the ultraviolet sensor array **50** and is displayed on the GUI **201** in the UV image. Because four separate image data objects are created (**655a, 655b, 655c** and **655d**), and the image produced by each image data object **655a, 655b, 655c** and **655d** can be viewed individually or in combination with the others, there are sixteen possible image views for display on the GUI **201**.

[0080] Also illustrated in **FIG. 6** is an area calculation processor **670**. The area calculation processor **670** runs algorithms using information stored in the image object database **645** in order to determine the area of a deformation region. Algorithms include, but are not limited to, Pick's theorem, Simpson's rule, a Monte Carlo method of quasirandom computation, and combinations of these algorithms. In some exemplary embodiments, user input may be used to help define a deformation region. The image update processor **660** receives user input and communicates with area calculation processor **670** to provide feedback from a user **690** regarding a deformation area. The image update processor **660** also updates the HMI **200** to display updated deformation area information.

[0081] **FIG. 7** is an operational flow chart **700** for completing a scan using the surface deformation image analyzer **100**. First, in step **702**, an area of interest is identified and viewed for

any visible deformity or medical complication. In step **706**, once an area of interest is identified, the image analyzer **100** is turned on; thereby, supplying power to each sensor arrays **20**, **30**, **40** and **50**. In step **710**, a user initiates routine testing of each sensor array **20**, **30**, **40** and **50**. In further exemplary embodiments, testing may start automatically when the image analyzer **100** is turned on.

[0082] In the exemplary embodiment shown: the temperature sensors **32** of the temperature sensor array **30** are tested first in step **715**; followed by testing of the displacement sensors **22** in step **720**; followed by testing of the ultrasonic sensors (transducers) **42** in step **725**; and followed by testing of the ultraviolet LEDs **52** and the digital cameras **55** of the ultraviolet sensor array **50** in steps **730** and **735**, respectively. In further exemplary embodiments, testing of the sensor arrays **20**, **30**, **40** and **50** may be completed in any order or in an order specified by a user. In still further exemplary embodiments, one or more of the steps **715**, **720**, **725**, **730** and **735** may be performed simultaneously.

[0083] In conducting the tests in steps **715**, **720**, **725**, **730** and **735**, each sensor in the respective arrays is tested in sequence. If any sensor fails, the image analyzer **100** is turned off and on again (step **706**), and the testing sequence of steps **715**, **720**, **725**, **730** and **735** is repeated until all sensor pass

testing. If any sensor continues to fail testing, the GUI **201** may prompt a user to complete repairs on a particular sensor prior to using the image analyzer **100**. Once all sensors pass testing, at least two ultraviolet markers **56** are placed on the area of interest (step **740**). The ultraviolet markers **56** are used to properly overlay images. After the ultraviolet markers **56** are placed; the scan is run (step **745**).

[0084] In step **750**, the magnification of the image displayed on the screen is adjusted. It is desirable to enlarge an area of interest so that the area fills the display screen and the ultraviolet markers **56** are still visible. Depending on the HMI **200**, magnification may be adjusted using the GUI **201** or a hardware selector (e.g., dial, slide, etc.).

[0085] Next, in step **755**, the area of the deformation is calculated. In calculating the area of the deformation, the surface deformation image analyzer **100** applies Simpson's rule to the closed deformation shape - whether the shape is regular or irregular. To calculate the area of the deformation, using the HMI **200**; a user selects a number of points around the perimeter of the deformation. The points are connected with straight lines to create a polygon or any other geometric form, depending on the shape of the deformity, around the deformation. The image analyzer **100** generates a grid which overlays the polygon. The grid specifies the units of measurement and may be in

inches, centimeters, or any other unit appropriate for the deformation.

[0086] The entire area of the polygon is then calculated using Pick's theorem. Pick's theorem calculates the area (A) of a polygon based on the number of grid points located in the interior of the polygon (i) and the number of grid points located on the polygon's perimeter (b) by using the following equation:

$$A = r^2 \left(i + \frac{b}{2} - 1\right)$$

where r is the scaling factor measuring the spacing between grid points.

[0087] Simpson's rule is then used to calculate the areas of any non-deformation regions included in the polygon that are formed by a simple closed polynomial curve. Simpson's rule may be written as

$$Area = \int_a^b f(x)dx \approx \frac{h}{3}\left[y_0 + 4y_1 + 2y_2 + \ldots + 4y_{n-1} + y_n\right]$$

where y_i are variable heights lying perpendicular to the x axis and $h = \frac{b-a}{n}$ is the length of the curve divided into n even numbered partitions.

[0088] For some non-deformation regions, the area must be rotated to form a simple closed polynomial curve. For rotated curves, when variable heights (x_i) lie perpendicular to the y axis, Simpson's rule can be written as

$$Area = \int_c^d f(y)dy \approx \frac{h}{3}\left[x_0 + 4x_1 + 2x_2 + \ldots + 4x_{n-1} + x_n\right]$$

where $h = \frac{d-c}{n}$ is the length of the curve divided into n even numbered partitions.

[0089] If a non-deformation region, after rotation and if necessary, has a shape such that a vertical line drawn over the curve would cross over open space, the region must be subdivided and the subdivided regions rotated. Small non-deformation regions may be ignored. In some instances, when the area of a deformation may be approximated by just the area of a polygon calculated by Pick's theorem, or subdivided into multiple polygons - the area of which add to an approximation of the deformation area, additional calculations using Simpson's rule may be omitted. For example, a crack in a hard surface may have primarily straight lines around the perimeter, and the area may be approximated using only Pick's theorem.

[0090] **FIGs. 8A-8D** illustrate an exemplary deformation, deformation polygon having an area calculated by Pick's theorem,

and non-deformation regions having areas calculated by Simpson's rule. A user will determine the points for forming the polygon for applying Pick's theorem, any non-deformation regions requiring the application of Simpson's rule (as well as those regions considered too small), and any non-deformation regions that must be subdivided for applying Simpson's rule. In some exemplary embodiments, a Monte Carlo method of quasi-random computation may be used in place of Simpson's rule to calculate the area under an irregular curve. After each non-deformation region area is calculated, the areas are totaled and subtracted from the area of the polygon calculated using Pick's theorem. The resulting value will be a close approximation of the area of the deformation.

[0091] In the exemplary embodiment described, the area of a deformation is calculated using the image generated by the ultraviolet sensor array **50** and captured by the digital cameras **55**. In step **760**, the HMI **200** may be used to call up images captured by individual sensor arrays or different overlay combinations of those images. Desired images, or overlaid images, are saved in step **765**. In step **770**, the deformation may be analyzed using the HMI **200**. For example, the HMI **200** may be used to determine displacement and temperature values of certain points in the deformation, or general comparisons and other measurements may be noted.

[0092] In some exemplary embodiments, the surface deformation image analyzer **100** may be used to track repairs or healing of deformations, or otherwise compare the effect of time on a deformation. When comparing current scanned data to previously scanned data for the same deformation; the images must first be returned to normal size (step **775**). In step **780,** the previous images are loaded (e.g., from internal memory, removable memory or remote memory) and compared to the current images (step **785**). In some exemplary embodiments, the current and past images may be overlaid for direct visual comparison and the overlaid images saved.

[0093] **FIG. 8A** illustrates an irregular deformation **102** on the surface of interest **101**. **FIG. 8B** shows the deformation **102** with points **110** marked on the perimeter of the deformation creating a polygon **115**. A grid **120** is overlaid on the polygon **115** and used to calculate the area of the polygon using Pick's theorem.

[0094] **FIG. 8C** illustrates the deformation **102** with the polygon **115**. Non-deformation regions **103a-f** and **104a-d** are shown as primarily closed polynomial curves. In the exemplary embodiment shown, the non-deformation regions **104a-d** are considered too small to impact an overall area calculation, while the non-deformation regions **103a-e** have areas which are calculated using Simpson's rule. In the exemplary embodiment

shown, the non-deformation region **103a** is oriented along the x-axis and does not need to be rotated for calculation, while the remaining non-deformation regions **103b-f** will need to be rotated for calculation.

[0095] As illustrated in **FIG. 8D**, when the non-deformation region **103e** is rotated so that the edge defined by the polygon **115** is along the x-axis, a vertical line **160** exists that passes through open space. The non-deformation region **103e** will need to be subdivided into two separate portions, such as along line **165**, in order to calculate the area using Simpson's rule. The two portions of non-deformation region **103e** may then be rotated along the y-axis for applying Simpson's rule. In further exemplary embodiments, a non-deformation region may be subdivided or partitioned using a single or multiple vertical or horizontal lines. In still further exemplary embodiments, a non-deformation region may be subdivided using a combination of vertical and horizontal lines.

[0096] It will be understood that many additional changes in the details, materials, steps and arrangement of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

SURFACE DEFORMATION IMAGE ANALYZER

ABSTRACT OF THE DISCLOSURE

A device is provided with integrated hardware and software components for measuring and monitoring abnormalities on animal and human tissue and other surfaces. The device includes a display panel and a control panel secured to the upper surface of a housing and a plurality of sensor arrays attached to the lower surface on two scanner belts. A processor receives input from the sensor arrays to create data objects which are stored in an image object database. A retrieval component retrieves the image objects and identifies attributes to display image and quantitative values on a the display panel. A hardware processing component runs at least one algorithm to determine the area of a surface abnormality. Another hardware processing component is provided to receive user input to update images and to select a deformation region for area calculation.

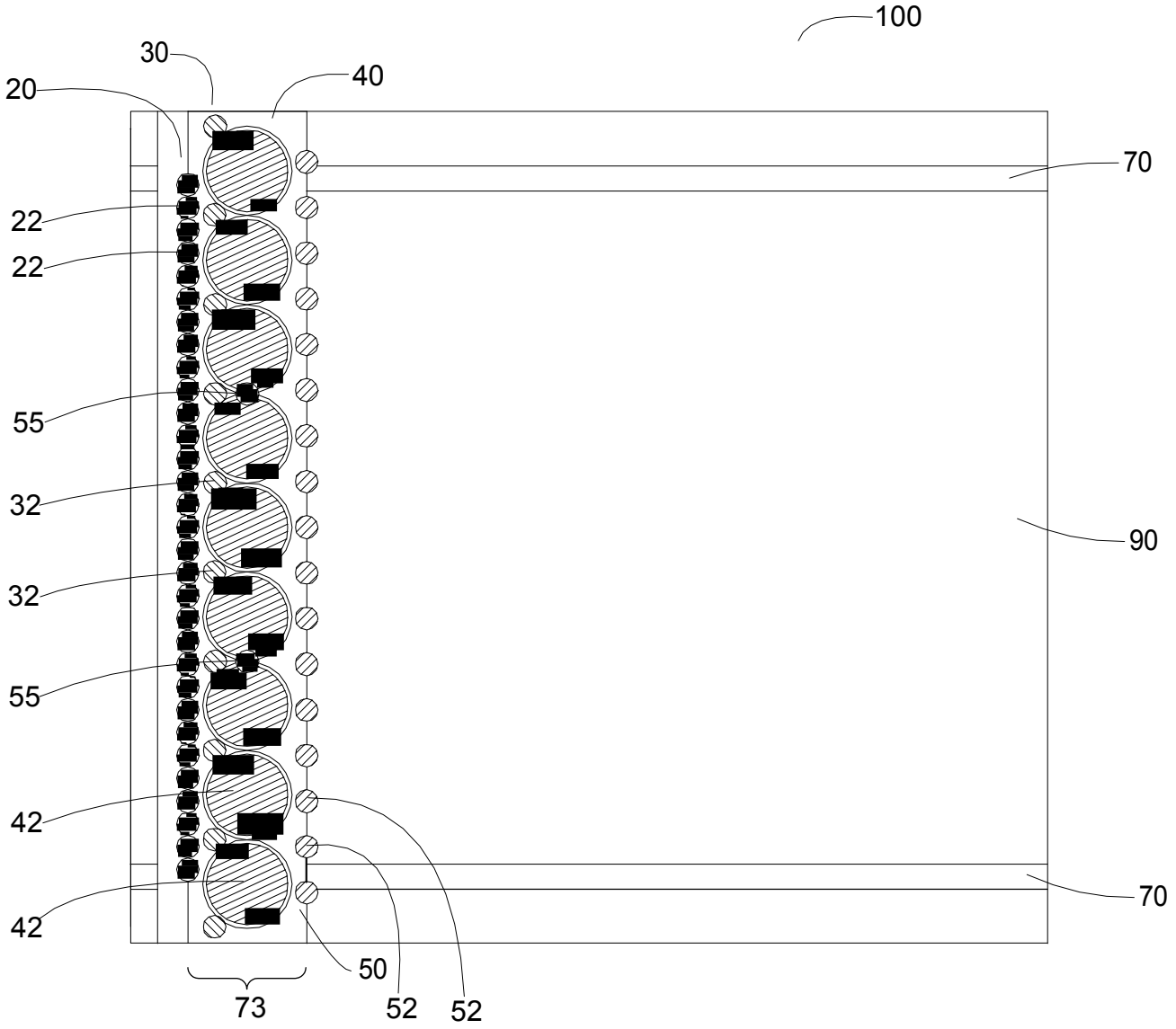

FIG. 1

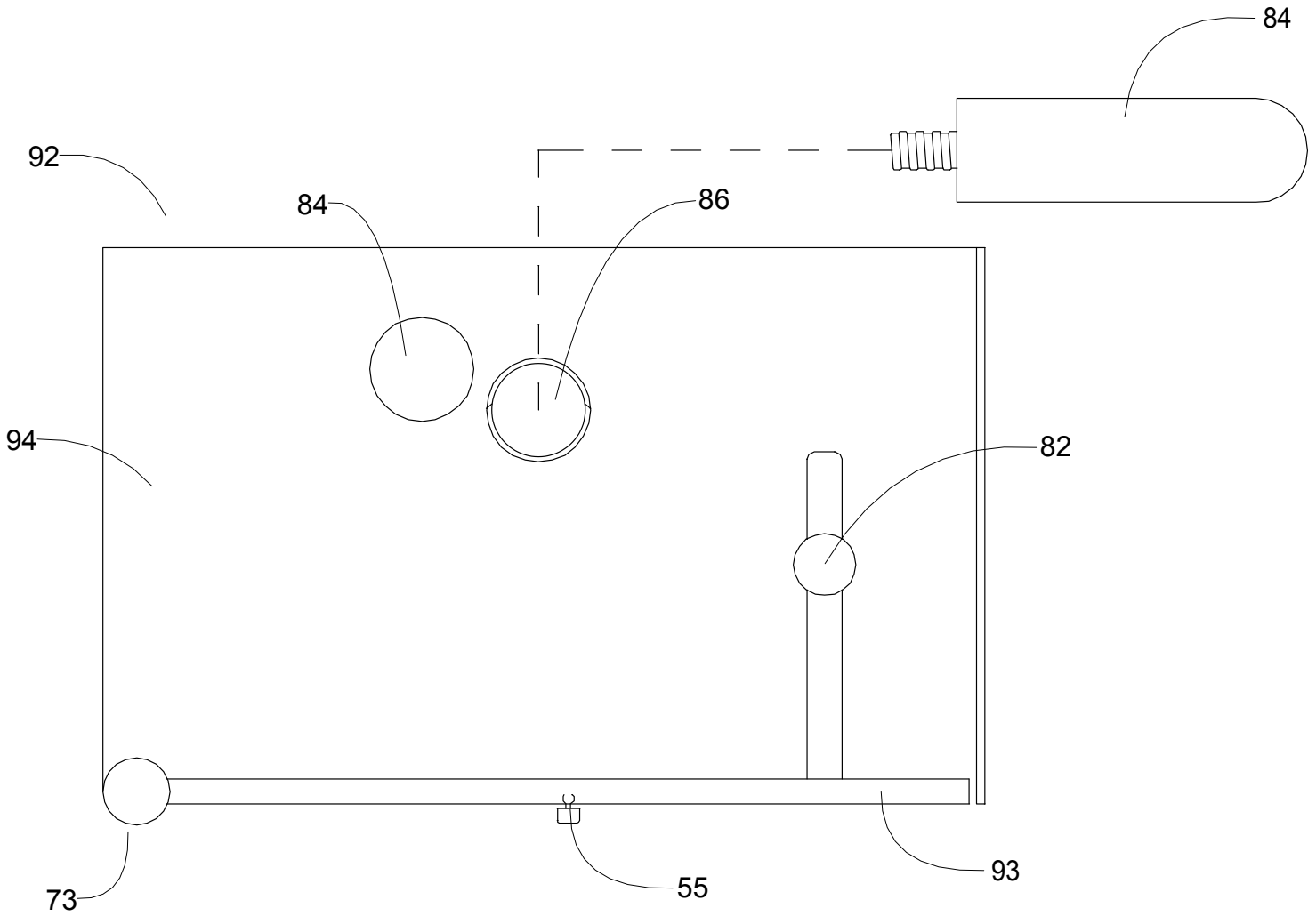

FIG. 2

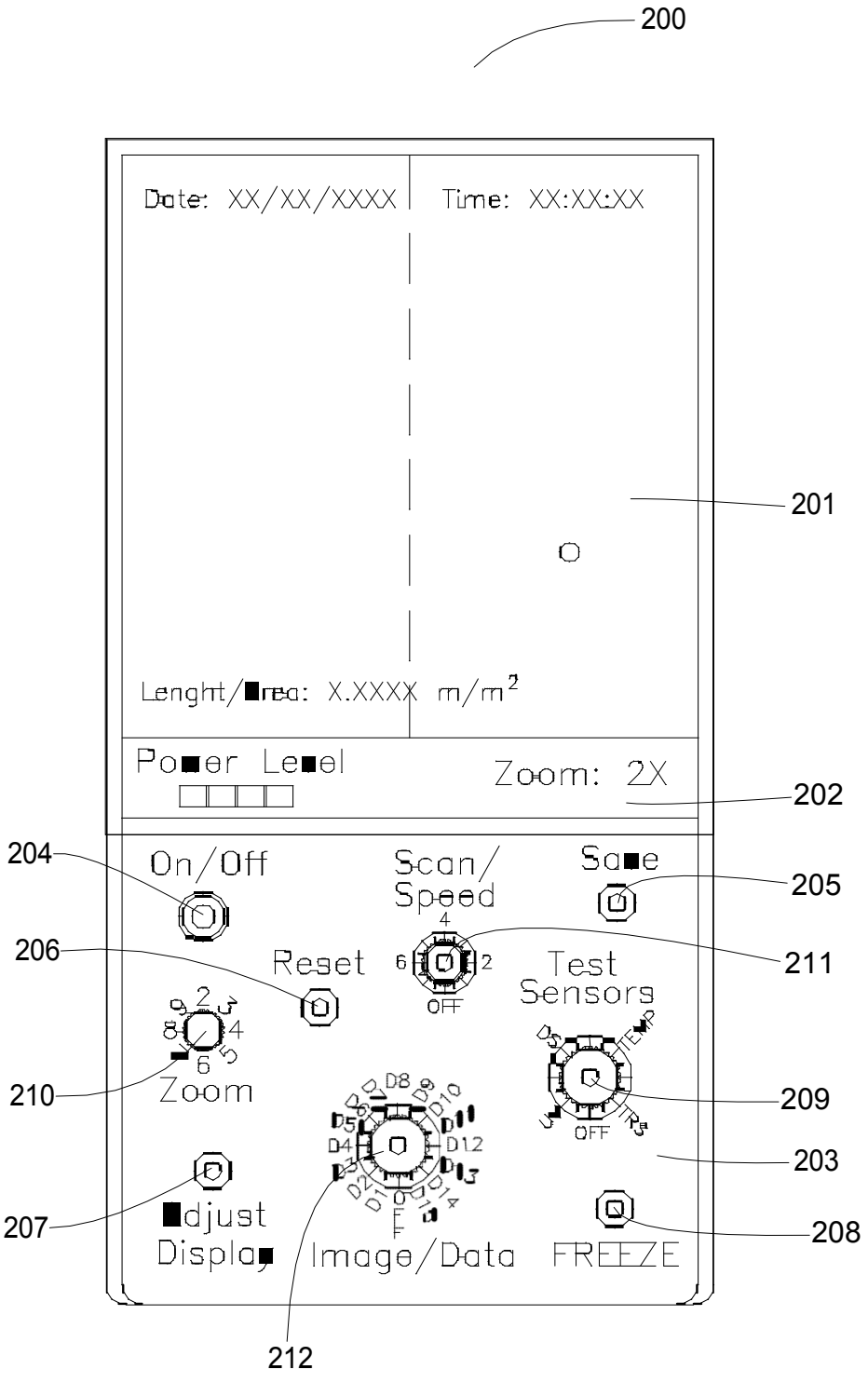
200
Date: XX/XX/XXXX
Time: XX:XX:XX
201
Lenght/Area: X.XXXX m/m²
Power Level
Zoom: 2X
202
204
On/Off
Scan/
Speed
Save
205
206
Reset
211
Test
Sensors
Zoom
210
209
OFF
203
Adjust
Display
Image/Data
FREEZE
207
208
212

FIG. 3

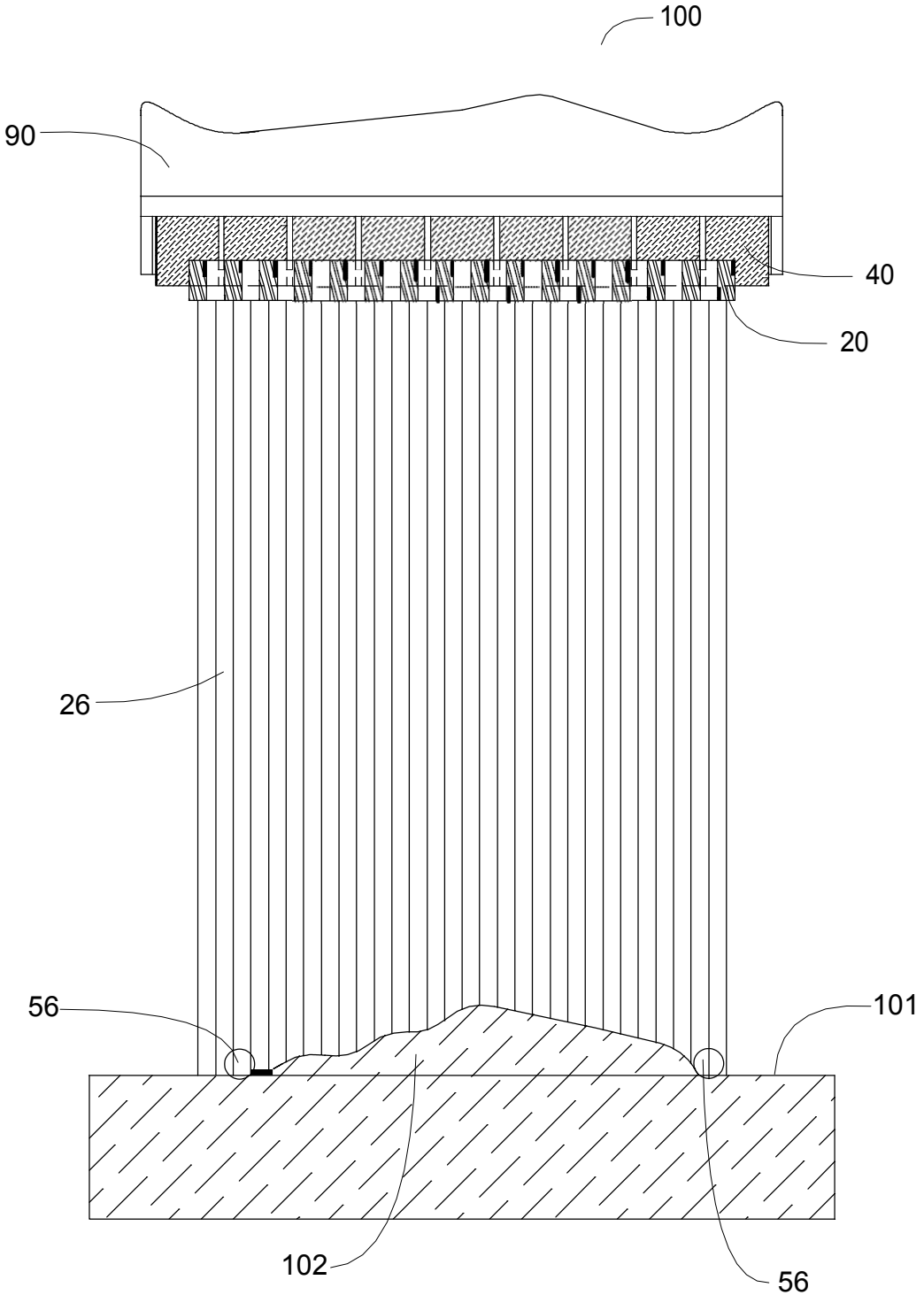

FIG. 4A

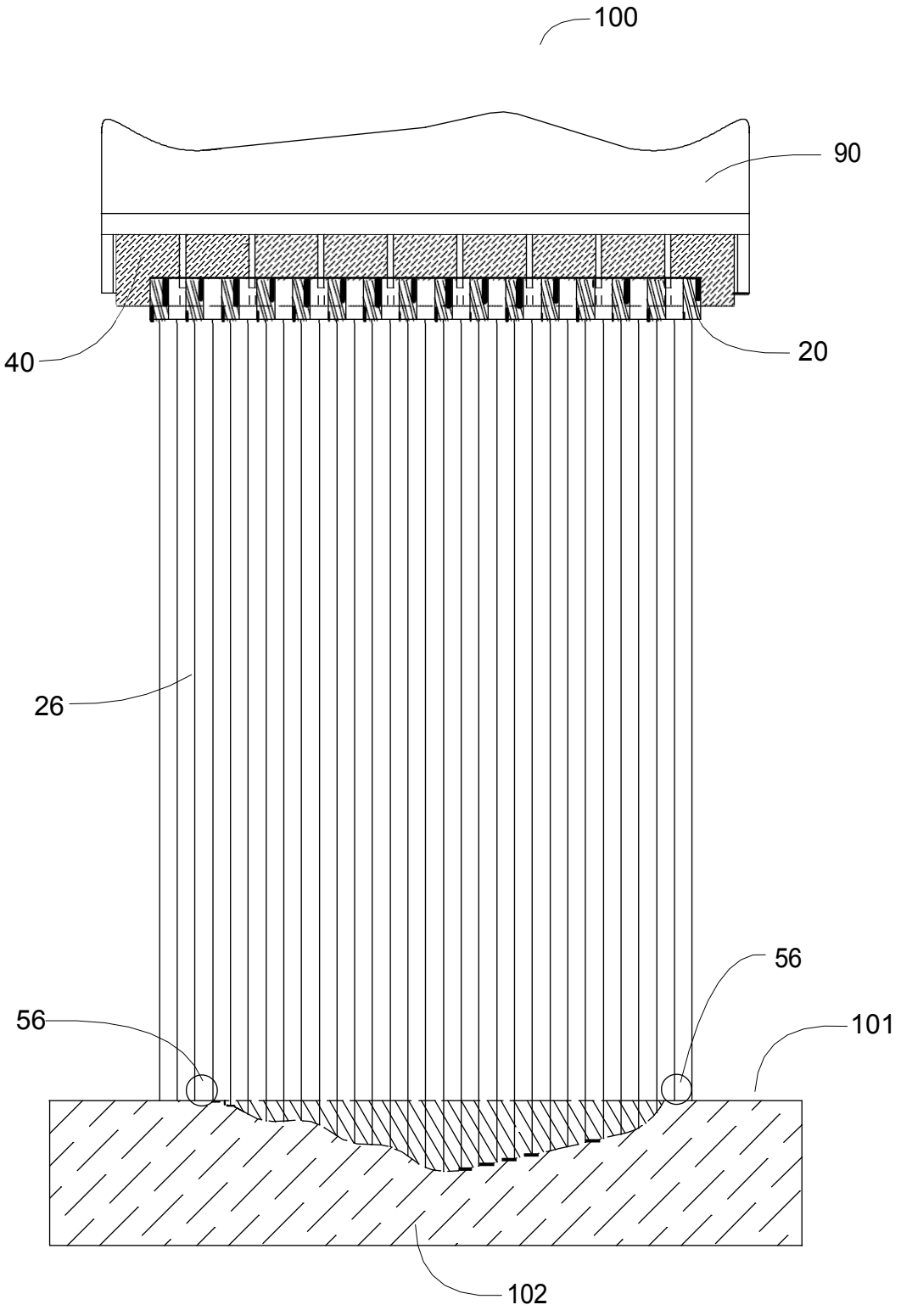

FIG. 4B

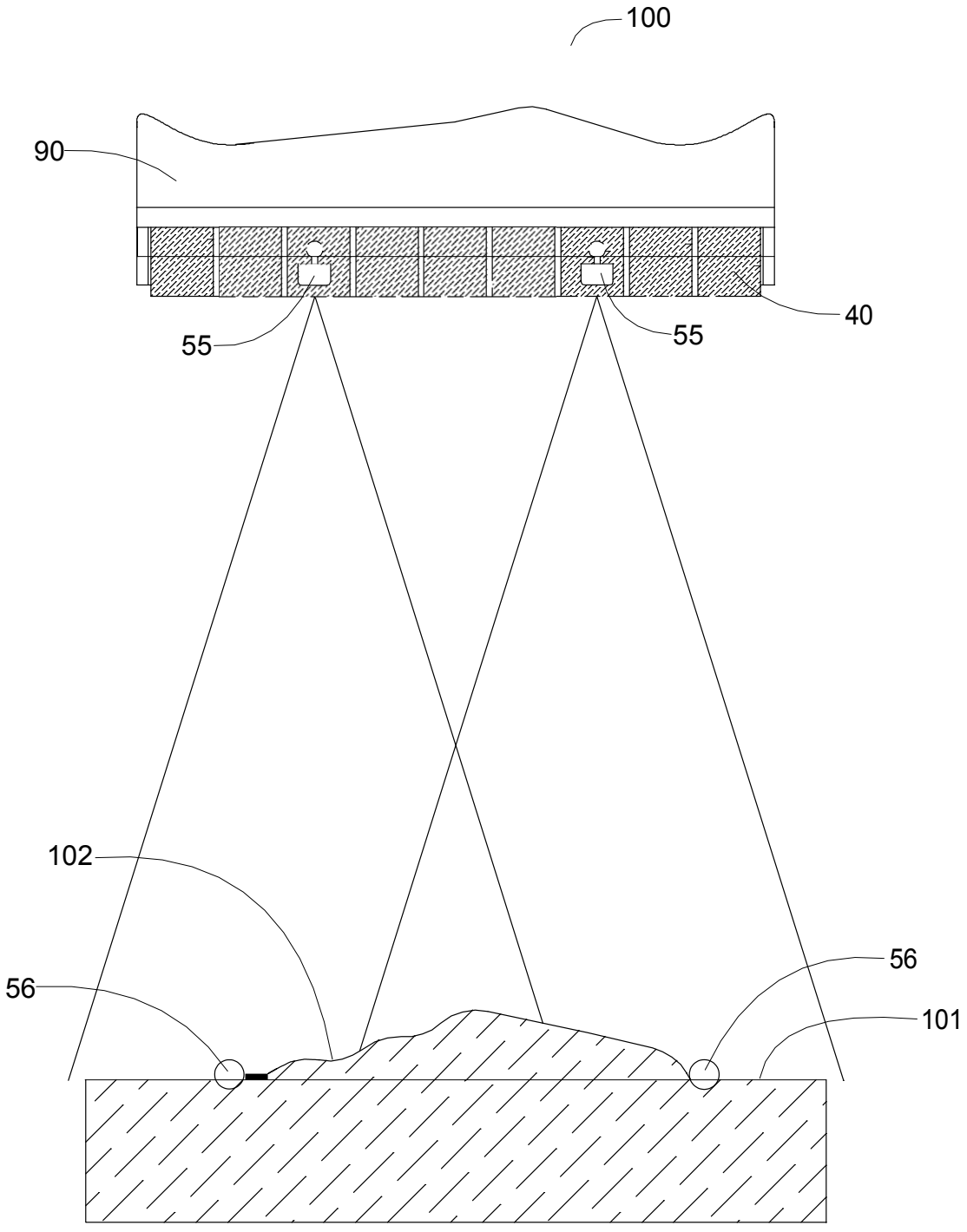

FIG. 5

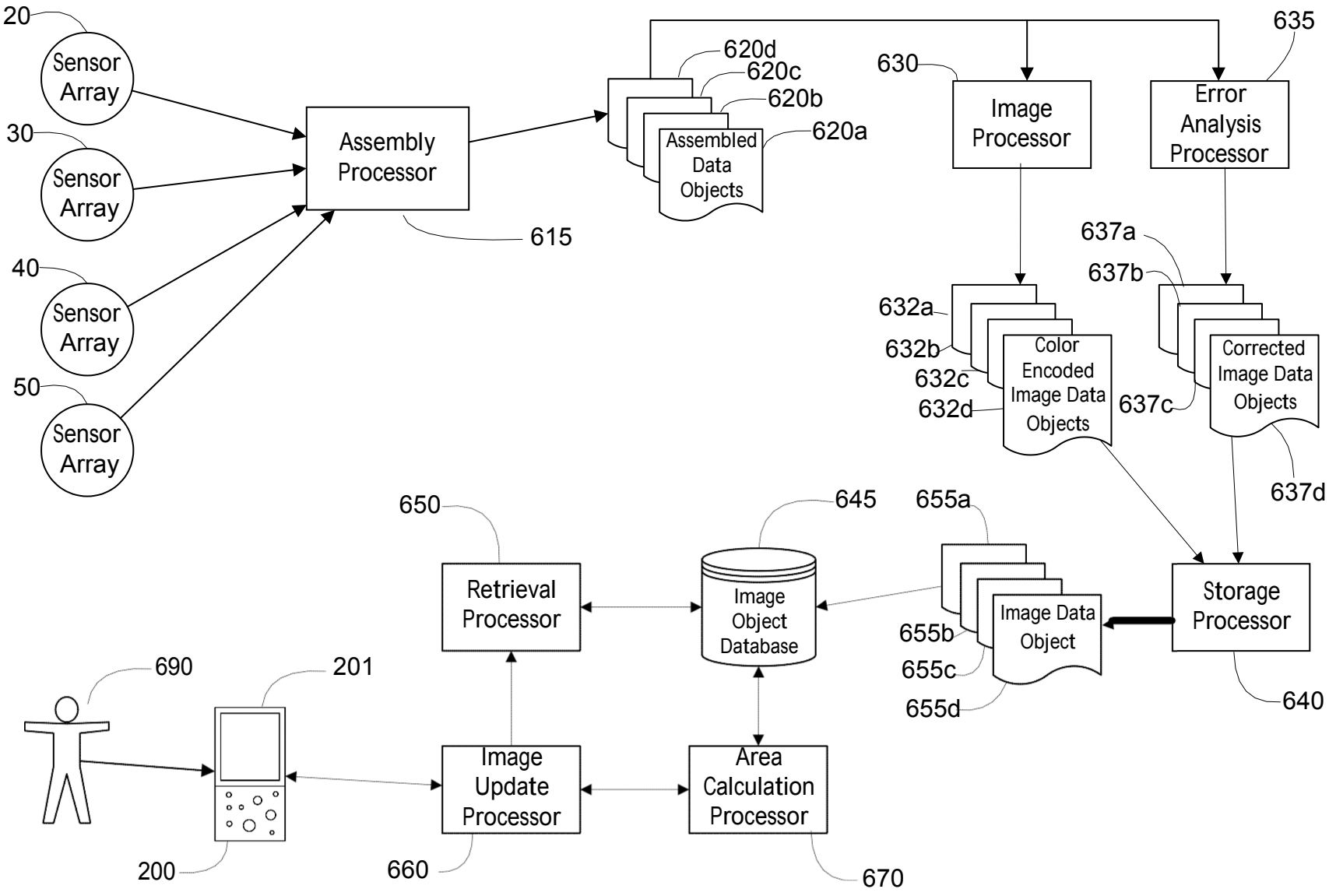
20
Sensor Array
30
Sensor Array
40
Sensor Array
50
Sensor Array
Assembly Processor
615
620d
620c
620b
620a
Assembled Data Objects
630
Image Processor
635
Error Analysis Processor
637a
637b
632a
632b
632c
632d
Color Encoded Image Data Objects
637c
Corrected Image Data Objects
637d
650
645
655a
Retrieval Processor
Image Object Database
Image Data Object
655b
655c
655d
Storage Processor
640
690
201
Image Update Processor
Area Calculation Processor
200
660
670

FIG. 6

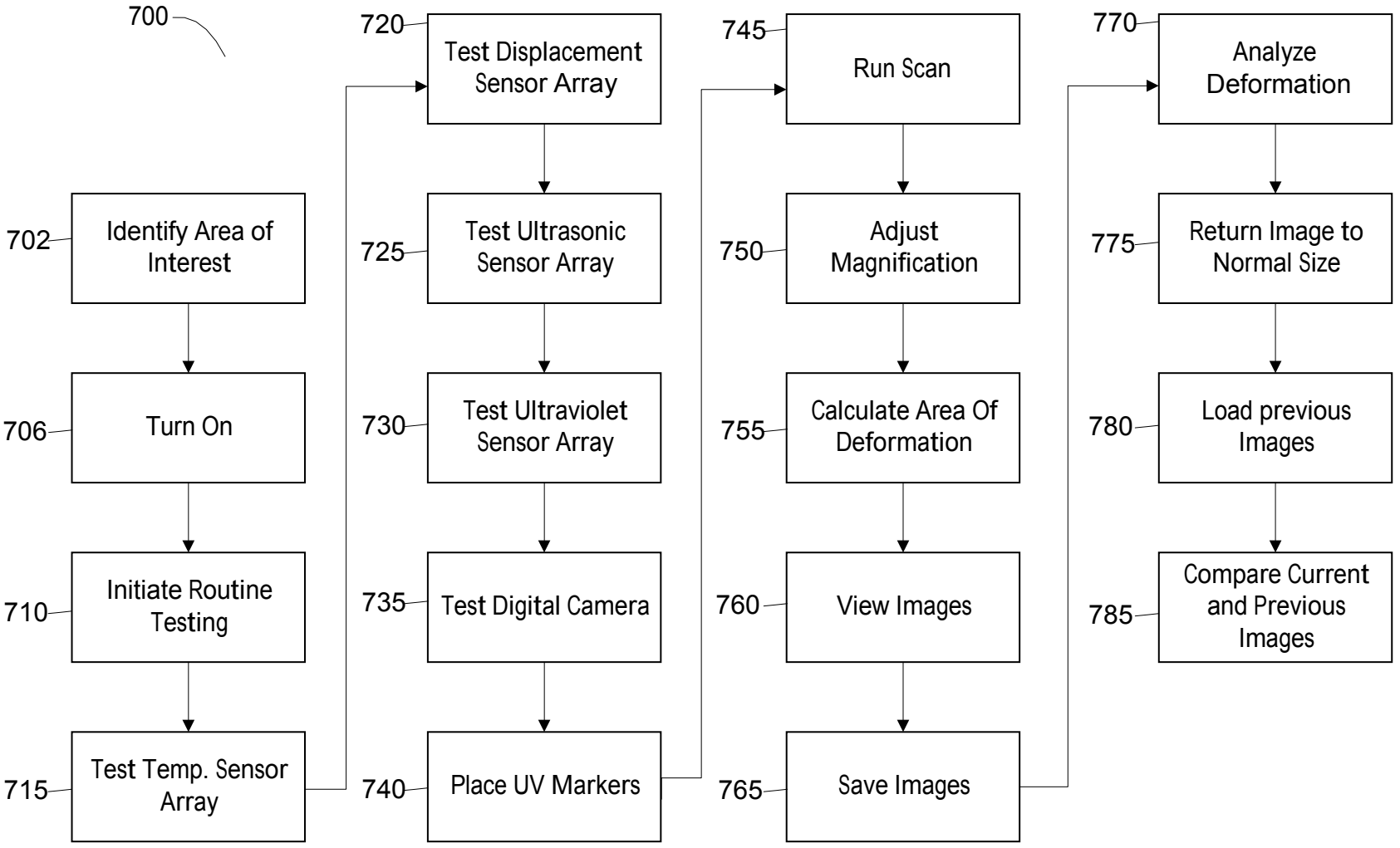
700
702
Identify Area of Interest
706
Turn On
710
Initiate Routine Testing
715
Test Temp. Sensor Array
720
Test Displacement Sensor Array
725
Test Ultrasonic Sensor Array
730
Test Ultraviolet Sensor Array
735
Test Digital Camera
740
Place UV Markers
745
Run Scan
750
Adjust Magnification
755
Calculate Area Of Deformation
760
View Images
765
Save Images
770
Analyze Deformation
775
Return Image to Normal Size
780
Load previous Images
785
Compare Current and Previous Images

FIG. 7

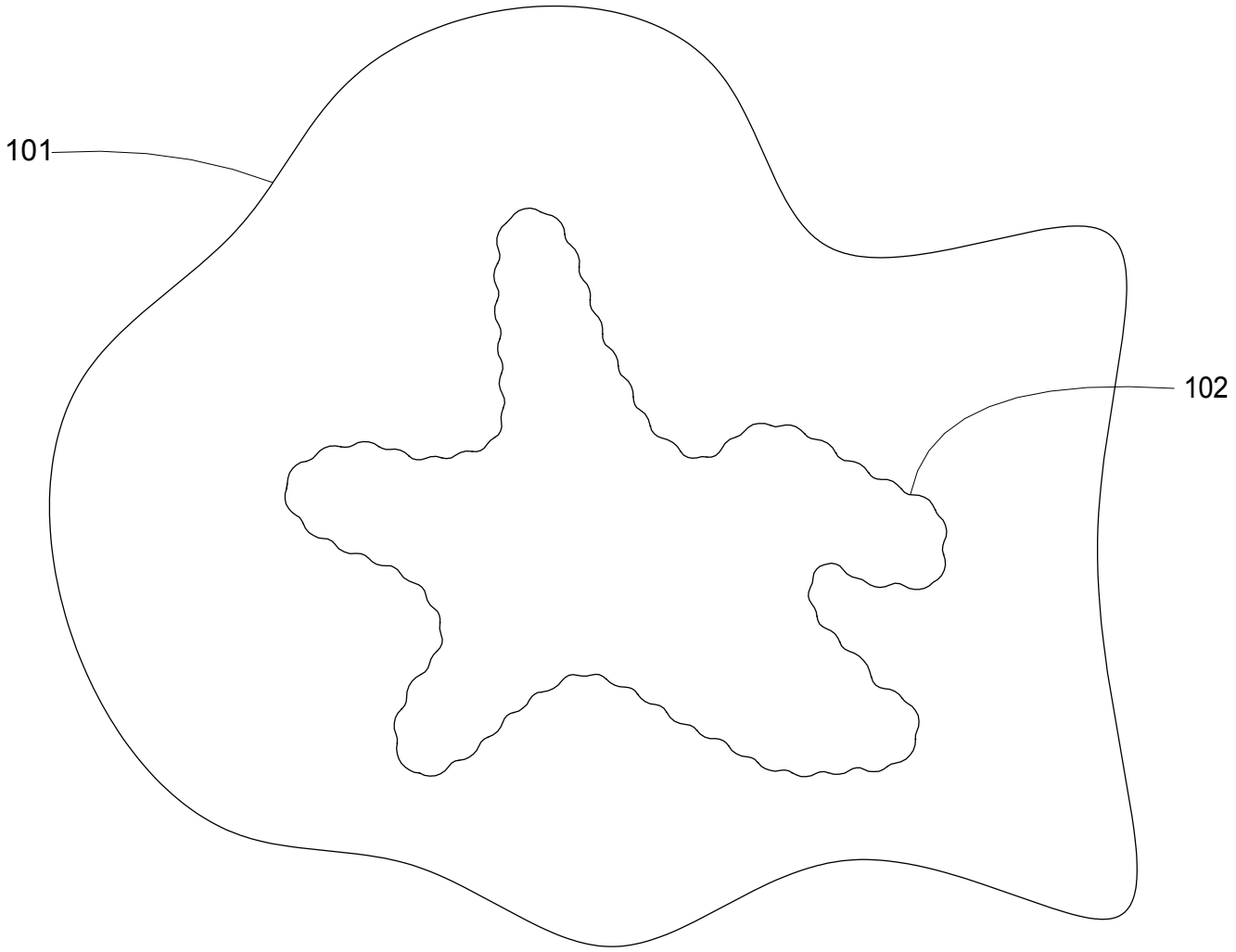

FIG. 8a

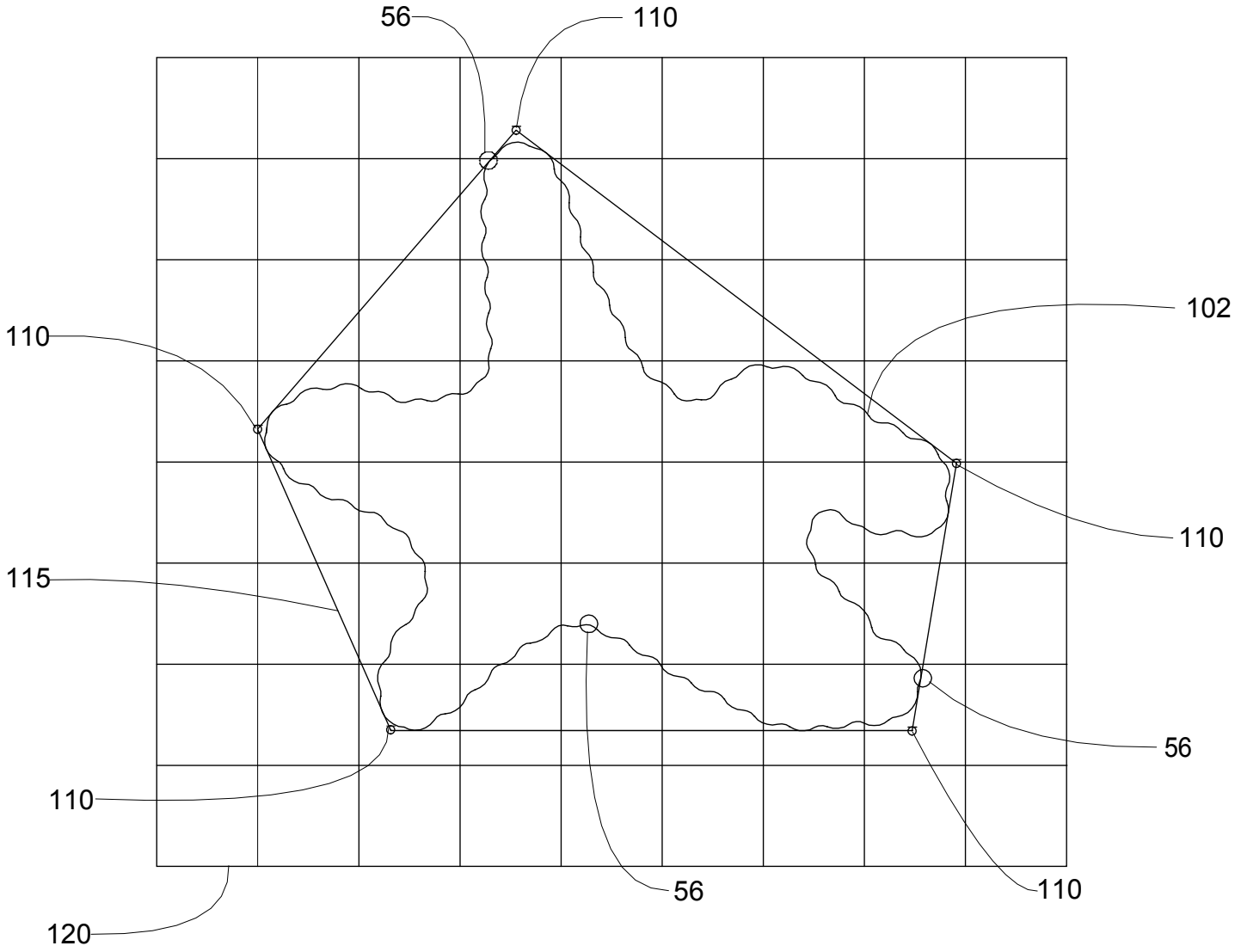

FIG. 8b

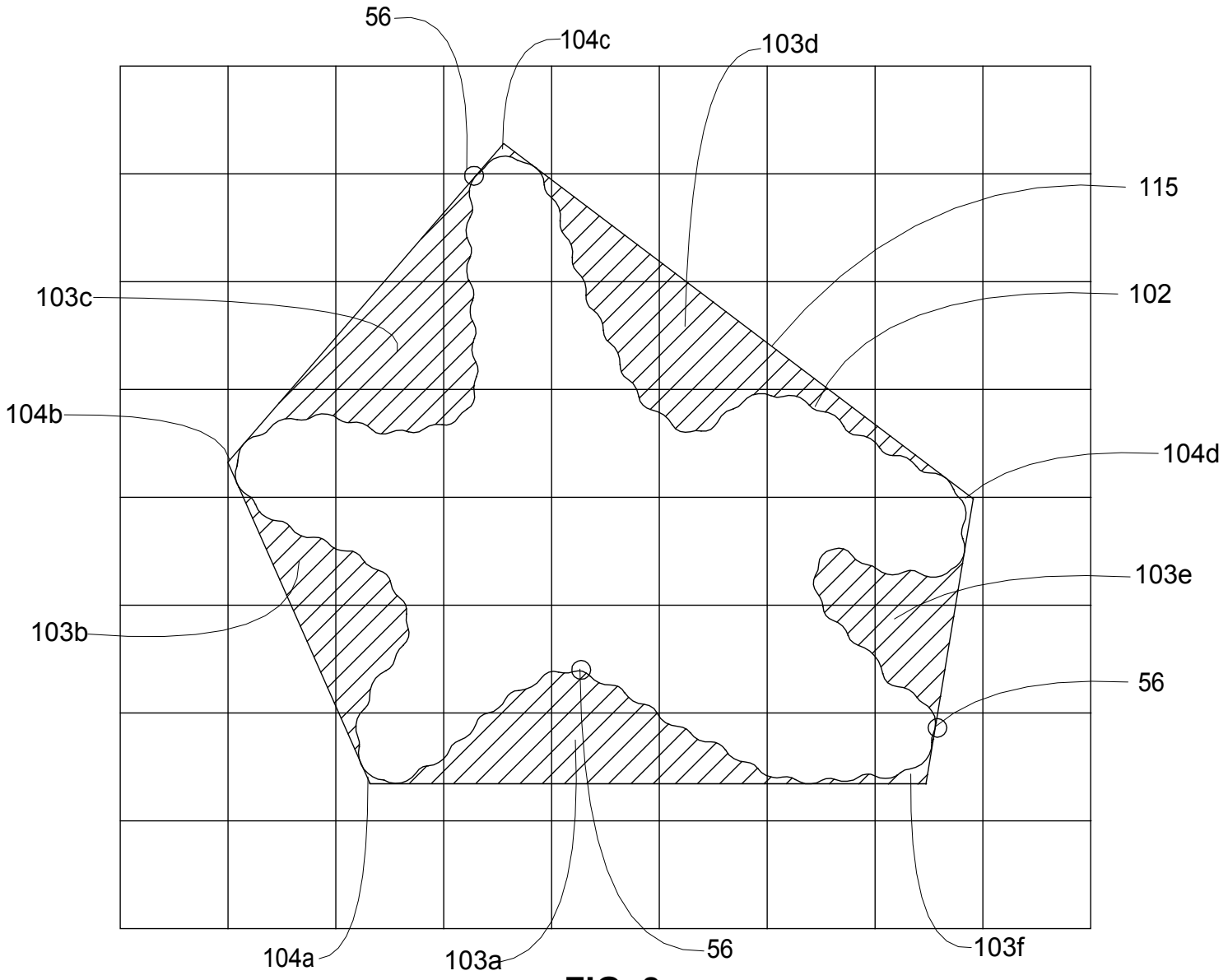
56
104c
103d
115
103c
102
104b
104d
103e
103b
56
104a
103a
56
103f

FIG. 8c

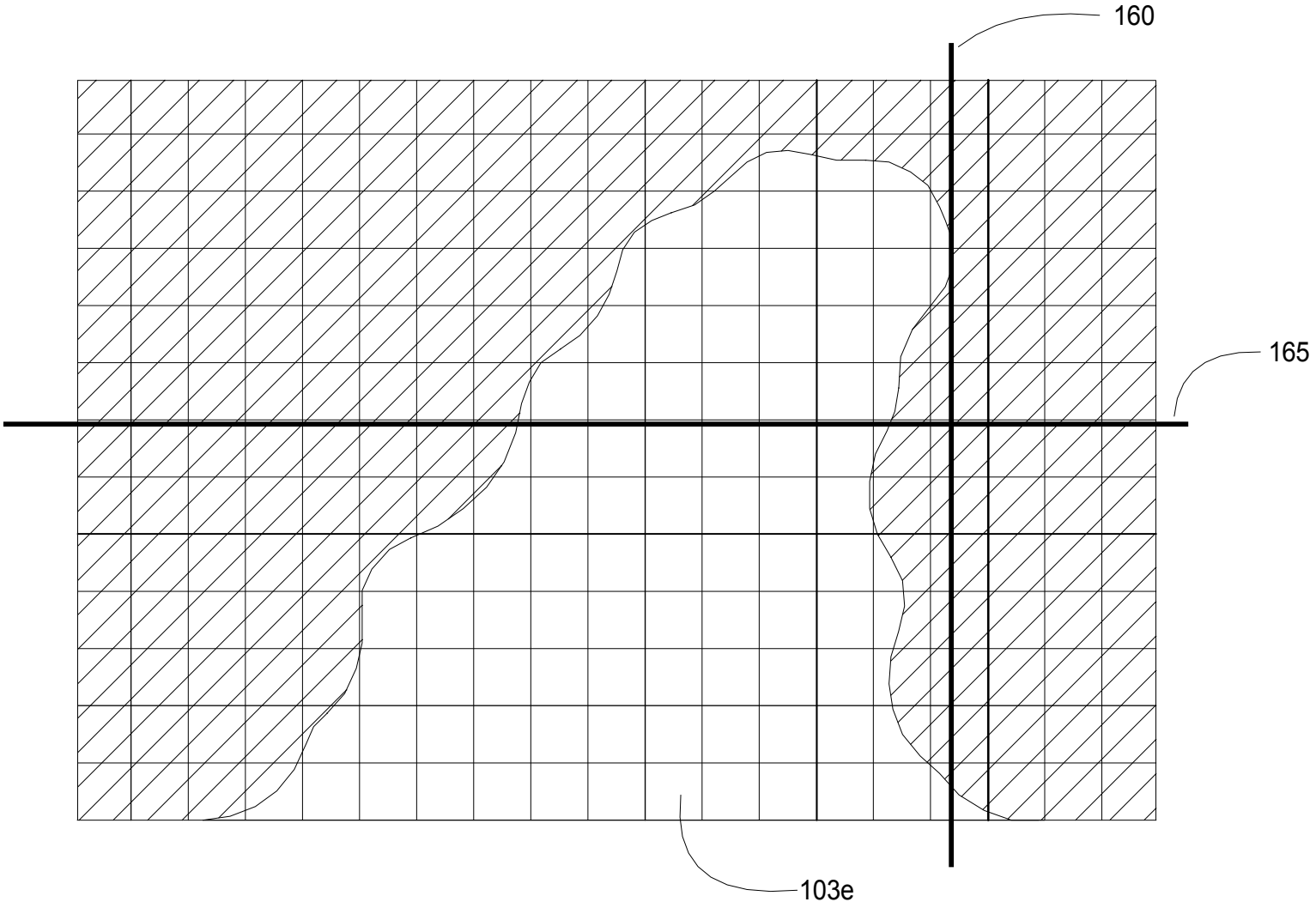

FIG. 8d